PART 4

LM2-TOXIC

Chapter 6. The LM2-Toxic Application and Interpretation

One of the important goals during the development of the LM2-Toxic was to quantitatively understand polychlorinated biphenyl (PCB) dynamics (i.e., transport and fate of PCBs) in the Lake Michigan system and delineate the relationship between PCB external loads and its concentrations in the system. For the following discussion, Lake Michigan refers to the main part of the lake (main lake) only, excluding Green Bay. Any references to the Lake Michigan system should be considered to include both Green Bay and Lake Michigan. Lake Michigan system = Lake Michigan + Green Bay. Main lake = Lake Michigan. After calibration of organic carbon and PCB congener dynamics and model confirmation, the LM2-Toxic was used as a mass budget diagnostic tool to identify the critical contaminant sources and sinks and key environmental processes in Lake Michigan and Green Bay. The model was also applied for forecasting the long-term responses of the Lake Michigan system to a variety of forcing functions and load reduction scenarios for PCBs. The mass budget analysis and the long-term forecasts under the specified load reductions were intended to provide information useful in making management decisions for the Lake Michigan system. Long-term PCB exposure concentrations predicted from the LM2-Toxic for various forcing functions and load reduction scenarios were provided to LM Food Chain as forcing functions to compute PCB concentrations in fish tissue.

4.6.1 Conversion of PCB Congener Results to Total PCBs

LM2-Toxic is a PCB congener-based model. It was developed to compute the concentrations, total mass, and mass movement (fluxes) of 54 PCB congeners in each compartment of the Lake Michigan system. These 54 PCB congeners account for about 63% to 85% of the total PCB mass in the various media (see Table 3.1.1 for the list of ratios between total PCBs and the summed modeling congeners in all media). There were enormous amounts of information related to the model inputs and outputs from the model on a basis of each PCB congener. For the efficiency and effectiveness of presenting the input information and results from the model, and for the convenience of the reviewers and readers, all numbers in this chapter are presented as total PCBs. The model outputs for each Lake Michigan Balance Project (LMMBP) selected PCB congener were first summed as ΣPCBs, and the ΣPCBs was then converted to total PCBs using a regression between total PCBs and ΣPCBs. The regression analysis for different media was done by Computer Sciences Corporation (CSC)/Large Lakes Research Station (LLRS) personnel and is detailed in Part 1, Chapter 3 of this report. The regression equations used in this chapter for the specified media are listed in Table 4.6.1. More information on regression equations for all media can be found in Table 1.3.1.

4.6.2 Mass Budget Diagnosis of the LM2-Toxic for the LMMBP Period

A mass budget diagnostic tool was developed within the LM2-Toxic in order to quantitatively analyze the

Table 4.6.1. Regression Equations Used for Converting ΣPCBs to Total PCBs for the LM2-Toxic Results

Media	Regression Equation	R^2
Dissolved Water	y = 1.2738x + 0.0268	0.9413
Particulate Water	y = 1.2251x + 0.0051	0.9992
Dissolved + Particulate Water	y = 1.2427x + 0.0347	0.9829
Surficial Sediment	y = 1.1668x + 0.6125	0.9970

behavior of PCBs in the Lake Michigan system. This tool has the ability to estimate very detailed PCB mass fluxes in the lake, mass inventories in different compartments of the lake, phase distributions, and contaminant residence times in the system. Therefore, the results of the mass budget diagnosis were used to demonstrate the most significant PCB sources and sinks and to identify key environmental processes in the Lake Michigan system.

A mass budget diagnosis was performed for each selected PCB congener modeled in the LM2-Toxic for the two-year LMMBP period (1994-1995). The final results of the mass budget diagnosis are presented as the annual total PCBs only. Figures 4.6.1 and 4.6.2 provide a summary of the results of the total PCB mass budget diagnosis and analysis in Lake Michigan and Green Bay. Figure 4.6.1 depicts the masses transported and inventories for the entire Lake Michigan system that includes Green Bay. Figure 4.6.2 depicts the mass transported and inventories for Green Bay separately from the main lake. Table 4.6.2 lists more detailed results of the total PCB mass budget analysis, including total PCB mass distributions in different phases and residence times in the system. The diagrams and table also give an indication of the importance for each environmental process conceptualized in the Lake Michigan system. The unit of the annual average mass fluxes (average of the two-year LMMBP period – 1994-1995) in the mass budget diagrams is in kg/year. The mass inventories in the diagrams for both water column and surficial sediment (0-4 cm) are the average mass at any time over the two-year LMMBP period and in units of kg. Due to seasonal variations in the concentration of both the water column and the surficial sediments in the Lake Michigan system, the numbers for inventories can be different on any given day in the LMMBP period. The average mass of total PCBs in the water column of the Lake Michigan system during 1994-1995 was 1,216 kg. About 30% (370 kg) of the total PCB mass in the water column was in the particulate phase (particulate detrital carbon [PDC] bounded + biotic carbon [BIC] bounded). Dissolved phase (dissolved organic carbon [DOC] bounded + unbounded) accounted for approximately 70% (846 kg) of the average mass of total PCBs in the water column. The average mass of total PCBs in the surficial sediments (0-4 cm) during the LMMBP period was 13,085 kg, and virtually all of the mass in the surficial sediment was bound to PDC. Based on the volumes of the water column (4.8148×10^{12} m^3) and the surficial sediment layer (1.0871×10^9 m^3) of the Lake Michigan system, the average concentration of total PCBs in the water column was 0.253 ng/L, and the average concentration of total PCBs in the surficial sediment layer was 12,037 ng/L. These concentrations were consistent with the average concentrations (0.259 ng/L for the water column and 650-25,000 ng/L for the surficial sediment layer) derived from the LMMBP field data.

Compared with Lake Michigan, the total PCB mass distributions in dissolved and particulate phases were quite different in the Green Bay water column. The inventories of particulate and dissolved PCBs in Green Bay were almost equal. The higher PCB mass in the particulate phase in Green Bay was due to the dominant tributary load from the Fox River. In the river, the particulate PCB concentrations were much higher than the dissolved PCB concentrations. In Lake Michigan, the particulate PCBs were less than half of the dissolved PCBs in its water column.

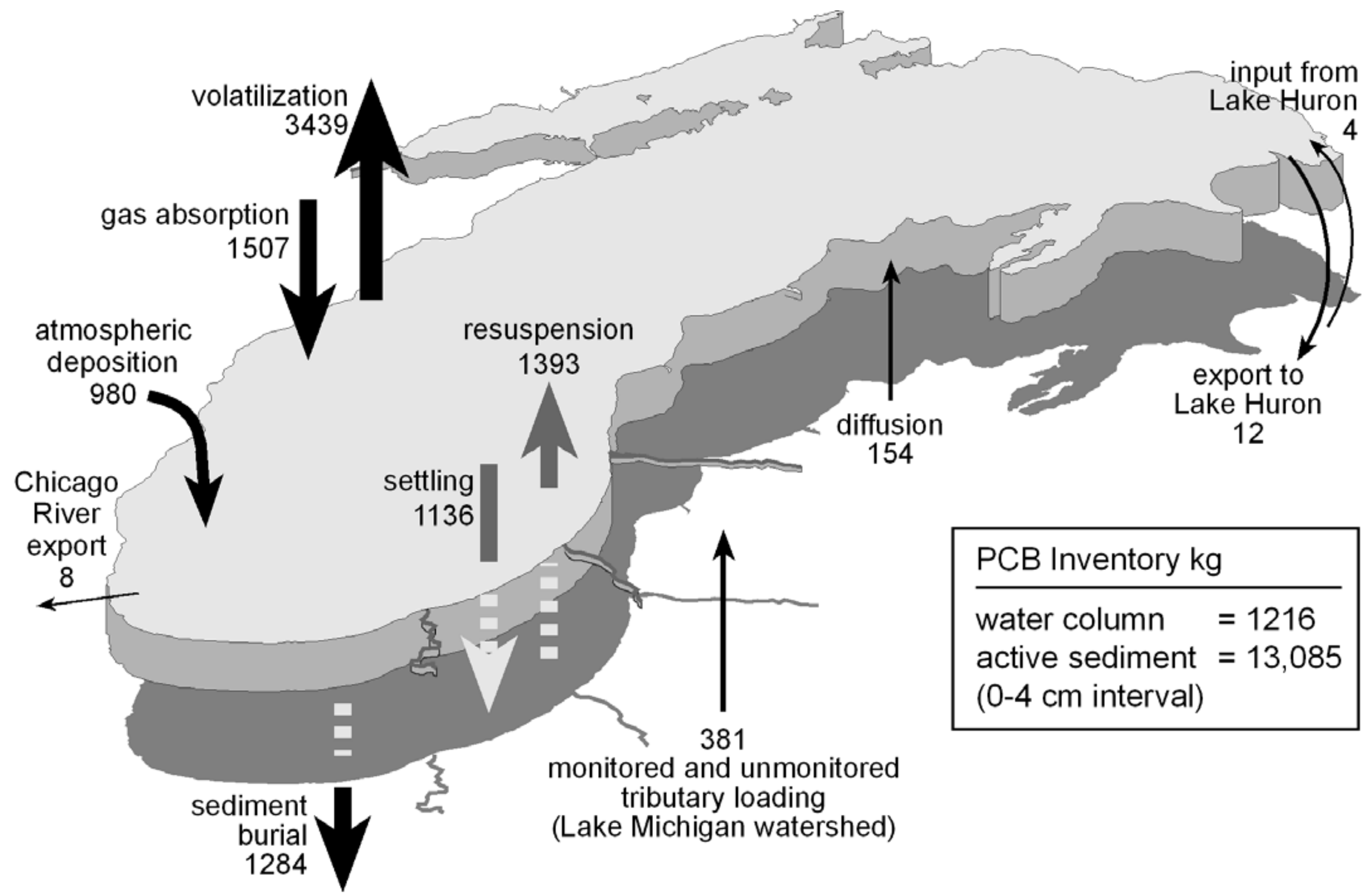

Figure 4.6.1. Mass budget average for 1994-1995 total PCBs in the Lake Michigan system (including Green Bay). Unit of the masses transported (arrows) is in kg/year.

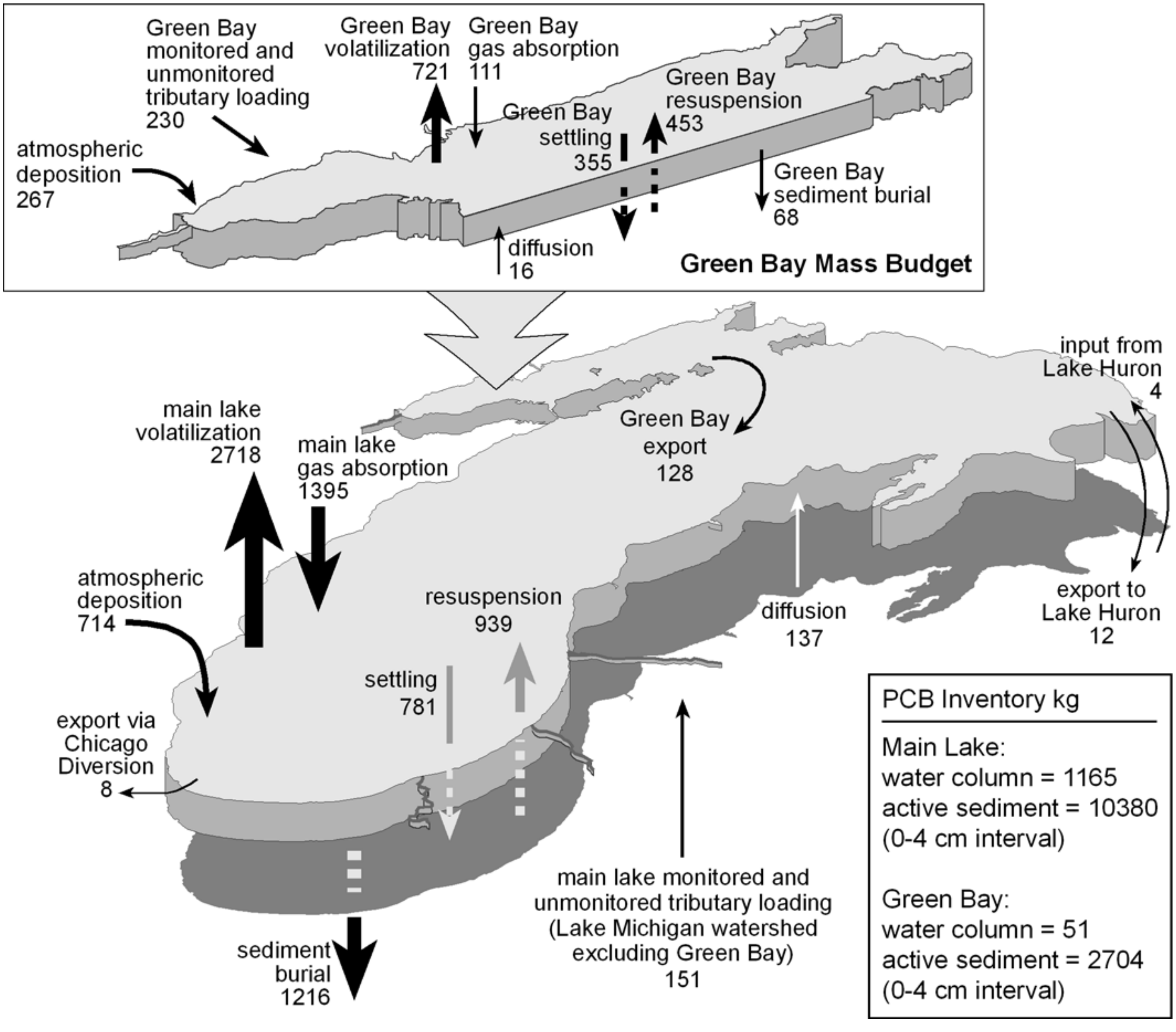

Figure 4.6.2. 1994-1995 total PCB Lake Michigan and Green Bay mass budget (averaged). Unit of the masses transported are in kg/year.

Table 4.6.2. Results of Total PCB Mass Budget Analysis for Lake Michigan and Green Bay (Fluxes are Annual Averages of the Two-Year LMMBP – 1994-1995; Inventories are the Average Inventories of the Two-Year LMMBP Period)

Mass Budget Component	Lake Michigan + Green Bay	Lake Michigan	Green Bay
Fluxes (kg/year)			
Total Loads	1362	865	496
(Monitored Tributary)	348	124	224
(Unmonitored Tributary)	33	26	7
(Atmospheric Dry)	767	514	253
(Atmospheric Wet)	214	200	13
Settling	1136	782	355
(PDC Bounded)	1076	764	311
(BIC Bounded)	61	17	44
Resuspension	1393	939	453
Burial (Sedimentation)	1284	1216	68
Diffusion	154	137	16
Absorption	1507	1395	111
Gross Volatilization	3439	2718	721
Net Volatilization	1932	1323	610
Input From Lake Huron	4	4	
Export to Lake Huron	12	12	
Net Output to Lake Huron	8	8	
Chicago Diversion	1	1	
Net Flux From Green Bay to Lake Michigan	128	128	128
Inventory (kg)			
Water Column	1216	1165	51
(PDC Bounded)	297	277	19
(BIC Bounded)	73	67	6
(DOC Bounded)	36	35	1
(Unbounded)	810	786	24
Surficial Sediment (0-4 cm)	13085	10380	2704
Residence Time in Water Column (Days)	97	121	17
Residence Time in Sediment (Days)	1688	1653	1837

Note: The fluxes represent the masses transported across the total area of an interface between adjacent compartments of the Lake Michigan system. Residence time for the water column was calculated by dividing the annual average inventory in the compartment by the annual total output (sum of gross volatilization, settling, export to Lake Huron, and Chicago diversion) from the water column. Residence time for the surficial sediment layer was derived by dividing the annual averaged sediment inventory by the sum of the losses (burial, resuspension, and diffusion).

The information on the individual fluxes of total PCBs in Figures 4.61 and 4.6.2 and Table 4.6.2 on an annual average basis for the LMMBP period provide further quantitative diagnosis on the importance of each source, sink, and the key environmental process in the Lake Michigan system. The single largest flux leaving the lake was gross volatilization (3,439 kg/year). This flux was countered by the flux from gas absorption (1,507 kg/year) as the largest source to the lake. The air-water exchange was the most important process for the Lake Michigan system. It accounted for the largest net loss (1,932 kg/year) from the Lake Michigan system of which 31.6% was from Green Bay (610 kg/year). Resuspension (1,393 kg/year) was a major flux into the water column of the Lake Michigan system. This was offset by the flux from settling (1,136 kg/year). The processes associated with the interaction between the water column and the surficial sediments (resuspension and settling) were very important processes in the Lake Michigan system. The results of these processes led to the second largest net source (257 kg/year) next to the total external load (1,362 kg/year) for the water column of the Lake Michigan system. About 40% of this net gain from the sediment-water interactions was contributed from Green Bay (98 kg/year). Green Bay received more than one-third (496 kg/year) of the total external load. The principal loss in the surficial sediment layer was burial (1,284 kg/year). The flux contributed by diffusion from the surficial sediment layer to the water column was 154 kg/year. The high value for the mass transported by the diffusion from the surficial sediment layer was not unexpected. The reason for the high value could lie in the selection of the diffusion coefficient used in the LM2-Toxic (1.73 x 10^{-4} m^2/day) (DePinto *et al.*, 1993) for sediment-water diffusion process. Compared with the coefficient used in the level 1 model (1.8 x 10^{-5} m^2/day, Table 3.3.2) and the coefficient defined under low-flow conditions for river sediment (1.5 x 10^{-4} m^2/day) (Ortiz *et al.*, 2004), the coefficient used in the LM2-Toxic was a bit higher. This could be another reason for the higher PCB concentrations for the bottom water segments output from the model during the LM2-Toxic PCB dynamics calibration (see Chapter 5 for details).

For the Lake Michigan system, the total external PCB load (monitored tributary, unmonitored tributary, atmospheric dry, and atmospheric wet loads) and input from Lake Huron was 1366 kg/year. The total output or loss was equal to 3,229 kg/year due to net volatilization, sediment burial, export to Lake Huron, and Chicago diversion. Therefore, there was a net loss of 1,863 kg/year of total PCBs from the entire Lake Michigan system. This indicated that both the water column and the surficial sediment layer of the lake were not at steady-state during the LMMBP period. By examining the mass fluxes of total PCBs in the water column alone, the annual average total gain (1,777 kg/year) during the project period was the sum of total external load, net resuspension (resuspension flux – settling flux) from the surficial sediment layer, diffusion from the surficial sediment layer, and input from Lake Huron. The annual averaged total loss for the water column during the same period was 1,945 kg/year and was equal to the sum of net volatilization, export to Lake Huron and Chicago diversion. Thus the water column experienced a total net annual loss of 168 kg/year. The annual average net export of total PCBs from Green Bay to Lake Michigan was equal to 128 kg/year during 1994-1995. The number is very close to the value (122.3 kg/year) estimated from the 1989 Green Bay Mass Balance Project (GBMBP) (DePinto *et al.*, 1993). A net loss of 1,695 kg PCB per year from sediment was due to burial below the surficial sediment (1,284 kg/year); net resuspension to the water column (257 kg/year = resuspension flux 1,393 kg/year - settling flux 1,136 kg/year); and diffusion (154 kg/year) from the surficial sediment layer to the water column.

Residence time for the water column was calculated by dividing the annual average inventory in the compartment by the annual total output (sum of gross volatilization, settling, export to Lake Huron, and Chicago diversion) to the water column. Therefore, the water column total PCB residence times for Lake Michigan including Green Bay, Lake Michigan only, and Green Bay only were approximately 97, 121, and 17 days, respectively. Similarly, the residence time for the surficial sediment layer was derived by dividing the annual averaged sediment inventory by the sum of the losses (burial, resuspension, and diffusion). Thus the total PCB residence times in the surficial sediment layer for Lake Michigan including Green Bay, Lake Michigan only, and Green Bay only were about 1,688, 1,653, and 1,837 days, respectively. Thus, PCBs reside in the surficial sediment layer much longer than in the water column of Lake Michigan.

4.6.3 LM2-Toxic Application for Long-Term Forecast and Sensitivity Scenarios

Predictions of long-term PCB dynamics under a variety of external forcing conditions were made using LM2-Toxic for seven PCB forecast and sensitivity scenarios. The model-predicted PCB concentrations were then used as the time-dependent exposure concentrations in the LM Food Chain to calculate PCB concentrations in lake trout. The simulation period for each scenario was 62 years, starting on January 1, 1994 and ending on December 31, 2055.

All scenarios used the same LMMBP-generated field data as input for the first two years (1994-1995) of the simulations. Then, each scenario began on January 1, 1996 and ran for a period of 60 years. The observed PCB total load for the LMMBP period (1994-1995) was adjusted upward by a factor of 1.98. The adjusted PCB load is consistent with the 1994 total load used in the PCB hindcast (see 1.7.3 of this report for details on the derivation of the PCB hindcast loading function) and is a reasonable estimate when considering the possibility of missing atmospheric loads during the LMMBP period (see 1.7.3 of this report for a detailed discussion).

The seven PCB forecast and sensitivity scenarios were:

A) Constant Conditions – The measured PCB loads (tributary load plus atmospheric dry and wet deposition) for the LMMBP period (1994-1995), but adjusted upward by a factor of 1.98. The adjusted loads followed the same spatial distribution and monthly variation patterns established by the LMMBP measured PCB loads. The adjusted loadings, the 1994-1995 vapor-phase concentration, Lake Huron boundary conditions, and all other forcing functions as observed in 1994 and 1995 were repeated throughout the simulation period. Sediment burial was active as well as all other model processes.

B) Continued Recovery (Fast) – This was the same as Scenario "A", but atmospheric components (vapor phase concentration, wet and dry deposition) declined with a six-year half-life (Hillery *et al.*, 1997; Schneider *et al.*, 2001), and tributary loads declined with a 13-year half-life (Endicott, 2005; Marti and Armstrong, 1990). The boundary conditions at the Straits of Mackinac declined at a rate of 0.17/year (a four-year half-life) (Schneider *et al.*, 2001). These rates were applied starting on January 1, 1996.

C) Continued Recovery (Slow) – This was the same as Scenario "A", but atmospheric components (vapor phase concentration, wet and dry deposition) declined with a 20-year half-life (Buehler *et al.*, 2002) and tributary loads declined with a 13-year half-life. The boundary conditions at the Straits of Mackinac declined with a four-year half-life. These rates were applied starting on January 1, 1996.

D) No Atmospheric Deposition – This was the same as Scenario "A", but starting on January 1, 1996, the atmospheric loads (dry and wet deposition) were set to zero. All other forcing functions as observed in the LMMBP period were repeated throughout the simulation period.

E) No Tributary Loadings – This was the same as Scenario "A", but starting on January 1, 1996, all tributary loads were set to zero. All other forcing functions as observed in the LMMBP period were repeated throughout the simulation period.

F) Lakewide Sediment Cleanup – This was the same as Scenario "A", but starting on January 1, 1996, the lake-wide sediment PCB concentration was instantaneously set to zero. All other sediment properties remained as existed prior to sediment clean-up. All other forcing functions as observed in the LMMBP period and processes were repeated throughout the simulation period.

G) No Atmospheric Deposition and No Tributary Loadings – The loading cuts of Scenarios "D" and "E" were combined. All other forcing functions as observed in the LMMBP period were repeated throughout the simulation period.

The results of the above seven scenarios will be presented in two separate groups. These are forecast scenarios (Scenarios A, B, and C) and sensitivity or engineering scenarios (Scenarios D, E, F, and G).

4.6.4 Results of the Forecast and Sensitivity Scenarios and Discussion

Figures 4.6.3 and 4.6.4 show the annual and monthly average long-term responses of total PCBs in the water column of the Lake Michigan system for the seven forecast and sensitivity scenarios. Compared to the annual lake-wide total PCB concentrations (Figures 4.6.3a and 4.6.3b), the monthly lake-wide total PCB concentrations show a much wider variation with high concentrations in the summer months and low concentrations in the winter months (Figures 4.6.4a and 4.6.4b).

The model results were compared to measured data and water quality criteria. The lake-wide average total PCB concentration (0.259 ± 0.172 ng/L) for the LMMBP period (1994-1995) was based on 298 field measurements from various water depths at 41 water column sampling stations. The total PCB concentration (0.165 ± 0.029 ng/L) from the Episodic Events-Great Lakes Experiment (EEGLE) project represents the average PCB concentration for southern Lake Michigan in 2000 (Miller, 2003). The focus of EEGLE was to investigate the potential impact of major sediment resuspension events on persistent organic pollutants (POPs) in southern Lake Michigan. Field sampling for EEGLE was conducted in 1998, 1999, and 2000. The average PCB concentration for 2000 from the EEGLE project was a better representation than the earlier years for the open-water concentration of PCBs in the lake and was used for post-audit comparisons to the results of the LM2-Toxic PCB long-term forecast and sensitivity scenarios. USEPA water quality criteria for the protection of wildlife is 0.12 ng/L and for human health is 0.026 ng/L; which is a human cancer value (HCV) that is still under review and development (U.S. Environmental Protection Agency, 2005; U.S. Environmental Protection Agency, 1997).

Scenario A – Constant Conditions serves as the upper bound of the range of possibilities resulting from the specified PCB forecast and sensitivity scenarios. The long-term response to the Constant Conditions Scenario clearly demonstrated that, during the LMMBP period (1994-1995), the Lake Michigan system was not at steady-state with respect to the 1994-1995 loads, vapor phase concentrations, and the level of sediment total PCB inventory. As the mass budget analysis indicated in the previous section and in Table 4.6.2, the mass losses from net volatilization and sediment burial were the major contributors to the decline of total PCB concentrations in both the water column and the surficial sediment layer. The spatially averaged steady-state value for the water column under this scenario was about 0.145 ng/L and was reached around 2024. This value represents a 44% reduction in the annual average concentration (0.259 ng/L) in the water column for the LMMBP period. The steady-state concentration of the Constant Condition Scenario will still be approximately 20% higher than the most recent (U.S. Environmental Protection Agency, 2005) USEPA water quality criteria for the protection and wildlife and five to six times higher than the USEPA water quality criteria for the protection of human health in the Great Lakes system (U.S. Environmental Protection Agency, 1997).

Among the forecast scenarios, the outcome from Scenario A (Constant Conditions) may not be a realistic prediction of long-term PCB concentrations in the lake. Because PCB production was phased out in the 1970s, PCB inputs into the Lake Michigan system through the atmosphere (*via* dry and wet deposition, and absorption of vapor phase) and tributaries have been decreasing significantly due to regulatory policies and remediation efforts made by federal and state agencies. Therefore, it is reasonable to assume that PCB inputs into the lake should continue decreasing under current regulatory policies and clean-up efforts. The decline rates used in Scenarios B and C for PCB inputs from the atmosphere and tributaries were the result of analyzing observed data collected for the past 25 years. These rates were subject to a certain degree of uncertainty (see Section 1.7.2). The variation of the estimated decline rates for atmospheric components (dry and wet deposition and vapor phase concentration) was quite large with half-lives ranging from 6 to 20 years. It appears that the rate of decline decreased with the addition of more recent data (Hillery *et al.*, 1997; Simcik *et al.*, 1999; Schneider *et al.*, 2001; Buehler *et al.*, 2002, 2004).

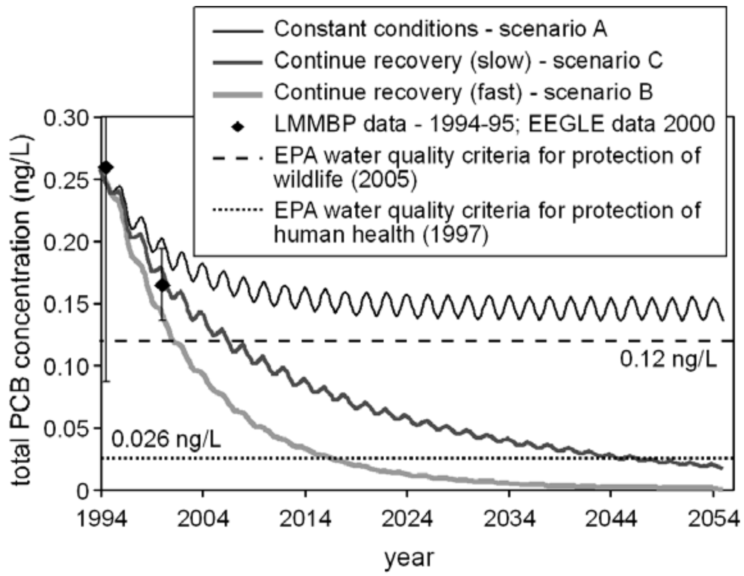

Figure 4.6.3a. Annual long-term responses to total PCB concentrations in the water column of Lake Michigan for the forecast scenarios and USEPA water quality criteria for the protection of wildlife (U.S. Environmental Protection Agency, 2005) and human health (U.S. Environmental Protection Agency, 2997) in the Great Lakes system.

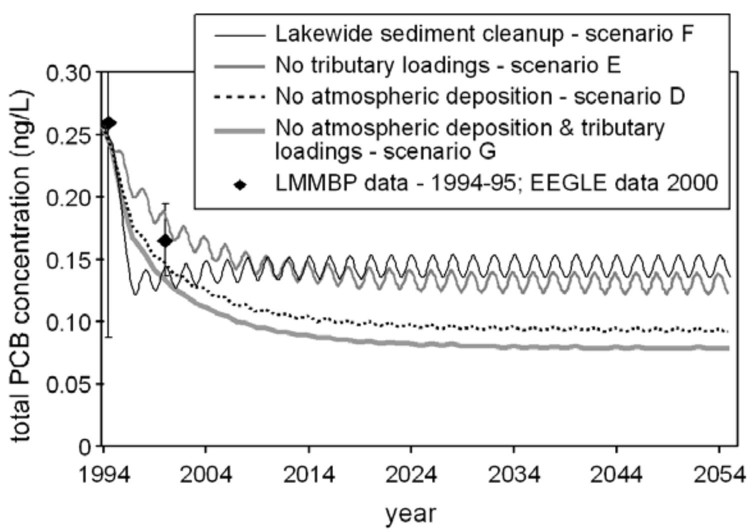

Figure 4.6.3b. Annual long-term responses to total PCB concentrations in the water column of Lake Michigan for the sensitivity scenarios.

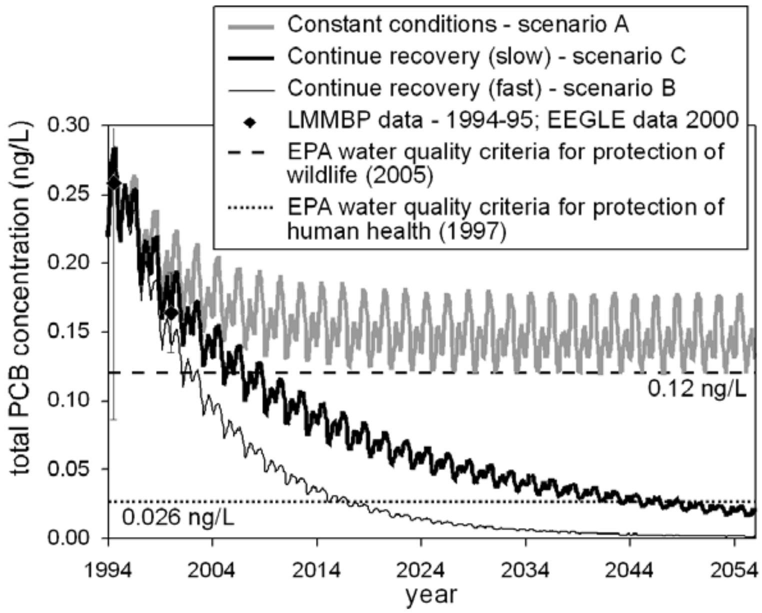

Figure 4.6.4a. Monthly long-term responses to total PCB concentrations in the water column of Lake Michigan for the forecast scenarios and USEPA water quality criteria for the protection of wildlife (U.S. Environmental Protection Agency, 2005) and human health (U.S. Environmental Protection Agency, 1997) in the Great Lakes system.

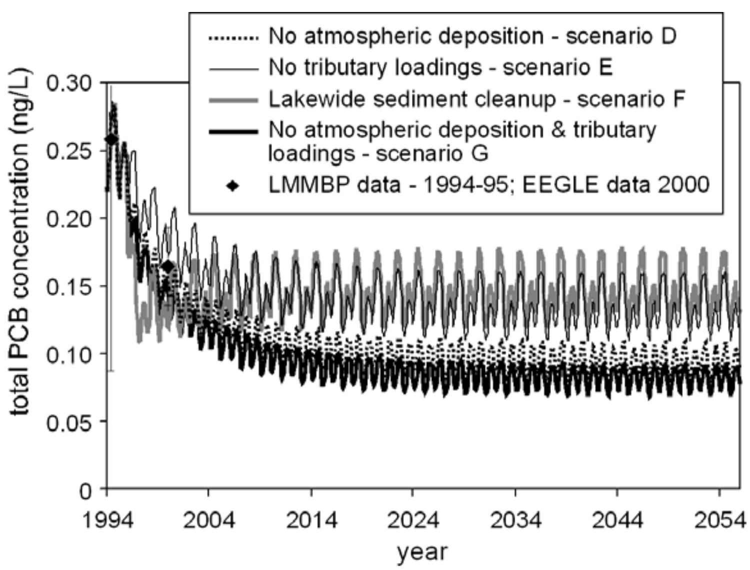

Figure 4.6.4b. Monthly long-term responses to total PCB concentrations in the water column of Lake Michigan for the sensitivity scenarios

The purpose of forecast Scenarios B and C was to provide bounds for predicted long-term PCB water column concentrations by assuming six-year half-life and 20-year half-life decline rates in PCB atmospheric components, respectively.

For Scenario B (Fast Continued Recovery Scenario), it takes about five years (starting January 1, 1996) for PCB concentrations in the water column to meet the USEPA water quality criteria for the protection of wildlife (U.S. Environmental Protection Agency, 2005) and more than two decades to reach the USEPA water quality criteria for the protection of human health (U.S. Environmental Protection Agency, 1997) in the Lake Michigan system. The water column PCB concentrations predicted in Scenario C (Slow Continued Recovery Scenario) declined at a much slower speed. The model results indicated that it would take about 12 years for the water column PCB concentrations in the lake to reach the USEPA water quality criteria for the protection of wildlife in the Great Lakes (U.S. Environmental Protection Agency, 2005). Figure 4.6.3a also shows that the PCB concentrations in the water column reached the USEPA water quality criteria for the protection of human health (U.S. Environmental Protection Agency, 1997) around 2046 (five decades after 1996). In both forecast Scenarios B and C, the PCB inventory in the surficial active sediment layer plays an important role in sustaining the water column PCB concentrations.

It is important to point out that the decline rate used in Scenarios B and C may not necessarily be realistic rates for the Great Lakes in the future. There is a chance that the actual rate could be slower, especially if there is no further regulatory and remediation actions taken to reduce the PCB sources from the atmosphere of the entire Lake Michigan watershed.

The sensitivity Scenarios D, E, F, and G were designed for the purpose of demonstrating how sensitive the long-term responses of the Lake Michigan system could be by hypothetically eliminating atmospheric deposition (dry and wet), tributary loads, total sediment inventory, and total external loads (dry and wet atmospheric deposition, and tributary loads altogether), respectively, starting on January 1, 1996. It is very important to mention that for these sensitivity scenarios, the PCB vapor phase concentrations were kept the same as the LMMBP (1994-1995) measured concentrations.

Long-term PCB concentrations in the water column were more sensitive to the atmospheric deposition (dry and wet) than the load from tributaries (Figure 4.6.3b). The steady-state concentration predicted from Scenario E (No Tributary Loadings) was 0.131 ng/L which was equivalent to less than a 10% decrease in the steady-state concentration (0.145 ng/L) from Scenario A (Constant Conditions). The steady-state concentration predicted from Scenario D (No Atmospheric Deposition) experienced a much larger drop to 0.094 ng/L, with a 35% reduction compared to the steady-state concentration of Scenario A. When eliminating both atmospheric deposition (wet and dry) and tributary load (Scenario G), the steady-state concentration decreased to 0.080 ng/L. By eliminating PCB total inventory in the lake sediments, starting on January 1, 1996, the PCB concentration in the water column experienced a steep drop initially and then gradually increased and reached a steady-state concentration of 0.145 ng/L. Notice that this value was the same as the one predicted from Scenario A (Constant Condition).

It should be emphasized that Scenarios D, E, F, and G are hypothetical and not realistic. Because LM2-Toxic was not coupled with an air quality model to dynamically compute PCB vapor phase concentration, the atmospheric concentrations in the sensitivity scenarios were kept constant as measured during the 1994-1995 LMMBP period. In reality, the PCB water column concentrations should be significantly lower than the steady-state concentrations resulting from these four sensitivity scenarios. As demonstrated in Figure 4.6.1, the gross volatilization flux is the largest flux moving PCB mass out of the lake. The decrease in the water column PCB concentrations after the actions taken for these four sensitivity scenarios would reduce the gross volatilization fluxes. As a result, the PCB vapor phase concentration over the watershed should decrease accordingly. This could lead to the reduction of PCB absorption flux to the lake and further reduce the PCB water column concentrations.

Figure 4.6.5 shows the long-term responses of PCB concentrations in the lake sediments to the seven forecast and sensitivity scenarios. In general, the PCB concentrations in the sediments followed

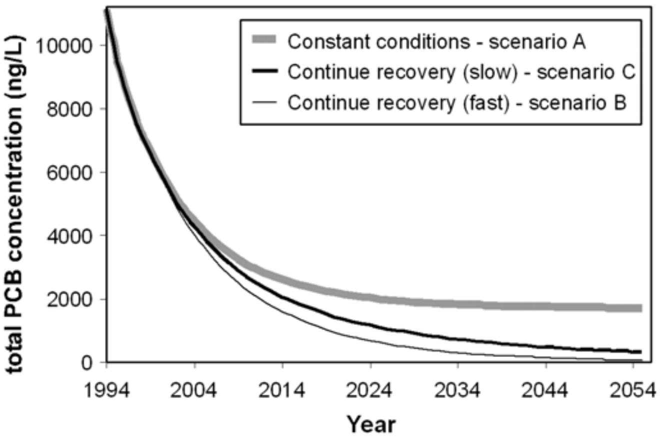

Figure 4.6.5a. Annual long-term responses to total PCB concentrations in the surficial sediment of Lake Michigan for the forecast scenarios.

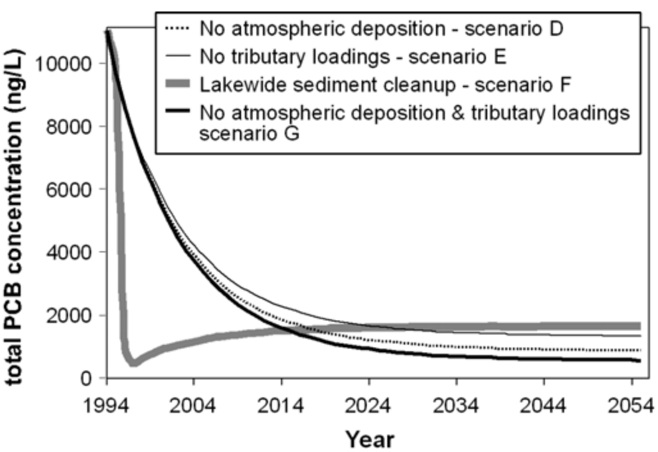

Figure 4.6.5b. Annual long-term responses to total PCB concentrations in the surficial sediment of Lake Michigan for the sensitivity scenarios.

similar long-term trends predicted for the water column. The steady-state PCB sediment concentration predicted from Scenario E (No Tributary Loads) was 1,347 ng/L which was 18% less than the steady-state PCB sediment concentration (1,665 ng/L) from Scenario A (Constant Conditions). The steady-state concentration predicted from Scenario D (No Atmospheric Deposition - Wet and Dry) was 909 ng/L which was 45% less than the concentration from Scenario A.

A few differences were noted when comparing responses of PCBs in sediment with the long-term responses of PCBs in the water column. First, there was no apparent seasonal variation in the long-term temporal profiles of the sediment PCB concentrations. The large PCB inventory and the mixing processes within the surficial sediment layer may have been factors smoothing out any seasonal variations caused by atmospheric components and tributary loads. Secondly, the long-term responses of PCB concentrations in sediment were more sensitive than those in the water column for the sensitivity Scenarios D (No Tributary Loads), E (No Atmospheric Depositions), and G (No Tributary and Atmospheric Loads). LM2-Toxic was developed for simulating 54 PCB congeners. Based on the data analysis results for PCBs in different media (see Part 1.6 for details), the heavier PCB congeners (higher molecular weight) were more abundant in tributary loads and atmospheric deposition (dry and wet) than in the vapor phase. In the water column, more than two-thirds of PCB mass was in the dissolved phase, and PCB concentrations were significantly influenced by PCB vapor phase concentration. Unlike in the water column, particulate PCBs in the lake sediments were the dominant phase, while PCBs in the dissolved phase were negligible. In addition, the heavier PCB congeners were more abundant in the sediments due to their higher partitioning coefficients. The larger percentage of heavy congeners in tributary loads and atmospheric deposition and the strong influence of vapor PCB concentrations on the water column PCB concentrations might be the factors making the PCB concentrations in sediment more sensitive to the tributary loads and atmospheric deposition than in the water column.

Reducing the PCB vapor phase concentration was critical to the level of long-term PCB concentration in the Lake Michigan system. Both Figures 4.6.3 and 4.6.5 (Scenarios B and C compared to Scenario A) demonstrate that the long-term response of PCBs in the lake system is very sensitive to PCB vapor concentrations. Figure 4.6.1 also shows that the volatilization flux and absorption flux are the number one and the number two fluxes for Lake Michigan. Again, the future declining rates for PCB atmospheric components (including vapor concentration, wet and dry deposition) may be slower than the rate used in Scenario C if there is no action taken in the future to continue reducing PCB vapor concentrations and particulate deposition from the atmosphere of the Lake Michigan watershed.

4.6.5 Results Provided for the LM Food Chain Model

The exposure concentrations generated from LM2-Toxic for the seven scenarios were provided as forcing functions to the LM Food Chain model to predict the long-term concentration changes for PCB congeners in lake trout tissue. Sets of exposure concentrations were generated for the Saugatuck biota box, segment 2, the Sturgeon Bay biota box, and segment 3 (see Figure 5.4.1 in Part 5 LM Food Chain for the locations of the biota zones). Each data set contained water column dissolved PCB concentrations (ng/L), water column particulate PCB concentrations (ng/g organic carbon), sediment dissolved PCB concentrations (ng/L), and sediment particulate PCB concentrations (ng/g organic carbon). Because there were multiple LM2-Toxic sediment segments under each biota box and water column segment, the sediment PCB concentrations provided to the LM Food Chain were computed using area-weighted averaging based on the segment-specific concentrations generated by the LM2-Toxic.

Field data for water column hypolimnetic total particulate PCB concentrations for the Saugatuck biota box was higher than for the much larger hypolimnetic level 2 segments (Segments 21, 30, 37) within which the Saugatuck biota box resided. Therefore, a factor of 1.5 was used to scale hypolimnetic water column total particulate PCB concentrations from the larger level 2 segments (Segments 21, 30, 37) to the hypolimnetic Saugatuck biota box. This factor was calculated based upon the LMMBP data collected from hypolimnetic sampling locations near the biota box and sampling locations within hypolimnetic segments 21, 30, and 37 as a whole (Table 4.6.3).

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Table 4.6.3. Mean and Median Particulate PCBs/Organic Carbon and Field Data and Scaling Factor for Hypolimnetic Level 2, Segments 21, 30, and 37, and for Saugatuck Biota Box Hypolimnion

Field Data	Segments 20, 29, 36 (Hypolimnion)	Saugatuck Biota Box, Hypolimnion	Factor
Mean Particulate PCBs/Organic Carbon (ngPCB/mgC)	0.560	0.817	1.5
Median Particulate PCBs/Organic Carbon (ngPCB/mgC)	0.509	0.747	1.5

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